



**You have downloaded a document from  
RE-BUŚ  
repository of the University of Silesia in Katowice**

**Title:** Late Triassic charophytes around the bone-bearing bed at Krasiejów (SW Poland) – palaeoecological and environmental remarks

**Author:** Michał Zatoń, Agnieszka Piechota, Elwira Sienkiewicz

**Citation style:** Zatoń Michał, Piechota Agnieszka, Sienkiewicz Elwira. (2005). Late Triassic charophytes around the bone-bearing bed at Krasiejów (SW Poland) – palaeoecological and environmental remarks. "Acta Geologica Polonica" (2005, vol 55, No. 3, s. 283-293).



Uznanie autorstwa - Użycie niekomercyjne - Bez utworów zależnych Polska - Licencja ta zezwala na rozpowszechnianie, przedstawianie i wykonywanie utworu jedynie w celach niekomercyjnych oraz pod warunkiem zachowania go w oryginalnej postaci (nie tworzenia utworów zależnych).



UNIwersYTET ŚLĄSKI  
W KATOWICACH



Biblioteka  
Uniwersytetu Śląskiego



Ministerstwo Nauki  
i Szkolnictwa Wyższego

# Late Triassic charophytes around the bone-bearing bed at Krasiejów (SW Poland) – palaeoecological and environmental remarks

MICHAŁ ZATOŃ<sup>1</sup>, AGNIESZKA PIECHOTA<sup>1</sup> & ELWIRA SIENKIEWICZ<sup>2</sup>

<sup>1</sup>Faculty of Earth Sciences, Będzińska Str. 60, PL-41-200 Sosnowiec, Poland. mzaton@wnoz.us.edu.pl;  
apiechot@wnoz.us.edu.pl

<sup>2</sup>Institute of Geological Sciences, Polish Academy of Sciences, Twarda 51/55 Street, 00-818 Warszawa, Poland.  
esienkie@twarda.pan.pl

## ABSTRACT:

ZATOŃ, M., PIECHOTA, A. & SIENKIEWICZ, E. 2005. Late Triassic charophytes around the bone-bearing bed at Krasiejów (SW Poland) – palaeoecological and environmental remarks. *Acta Geologica Polonica*, **55** (3), 283-293. Warszawa.

Thousands of Late Carnian (Late Triassic) charophyte gyrogonites belonging to four species [*Stellatochara germanica* KOZUR & REINHARDT, *Stomochara starozhilovae* (KISIELEVSKY), *Stenochara kisielevskyi* BILAN and *Porochara triassica* (SAIDAKOVSKY)] occur in the beds around the vertebrate-bearing level at Krasiejów, SW Poland. The abundant and well-preserved gyrogonites generally attest to fossilization *in situ*. Information about the habitat of recent charophytes is useful for reconstruction of their past environments. The factors limiting the habitat of modern charophytes suggests that these algae, and other micro- and macrofauna sedimented within the bone-bearing bed, lived in a shallow, freshwater environment (probably lacustrine). Above the bone bed, there is a rapid drop in gyrogonite abundance. This could have been caused by changes in environmental conditions: increase in salinity, or increase in water energy. The preliminary mineralogical data suggest arid to semi-arid climate.

**Key words:** Charophyta, Triassic, Carnian, Palaeoecology, *Paleorhinus*, Krasiejów, Poland.

## INTRODUCTION

Krasiejów is now known not only in Poland, but also worldwide, because of the spectacular finds of Late Triassic land vertebrates (DZIK & *al.* 2000; DZIK 2001, 2003; SULEJ 2002, 2005; SULEJ & MAJER 2005). Apart from reptiles and amphibians, there are numerous remains of charophytes (green algae). These algae, very widespread in recent times, are an important palaeolimnological tool (e.g. KOZUR 1971a,b, 1972; KOZUR & MOSTLER 1972; GARCÍA 1994; SOULIÉ-MÄRSCHÉ 1998; ANADÓN & *al.* 2000; BECKER & *al.* 2002; ANDREWS & *al.* 2004). They are useful for reconstructing the conditions (e.g. depth, salinity and turbulence) that prevailed during sedimentation in the basin.

In this article we present the preliminary conclusions about the charophyte palaeoecology during sedimentation of the bone-bearing bed (see DZIK & *al.* 2000) as well as the underlying and overlying beds.

## STRATIGRAPHICAL POSITION OF THE BEDS INVESTIGATED

Krasiejów is located in the Opole Silesia region in south-western Poland (Text-fig. 1). The deposits investigated consist of Upper Triassic dark red and grey claystones and mudstones. They are exposed in a clay mine belonging to the “Strzelce Opolskie” cement works.

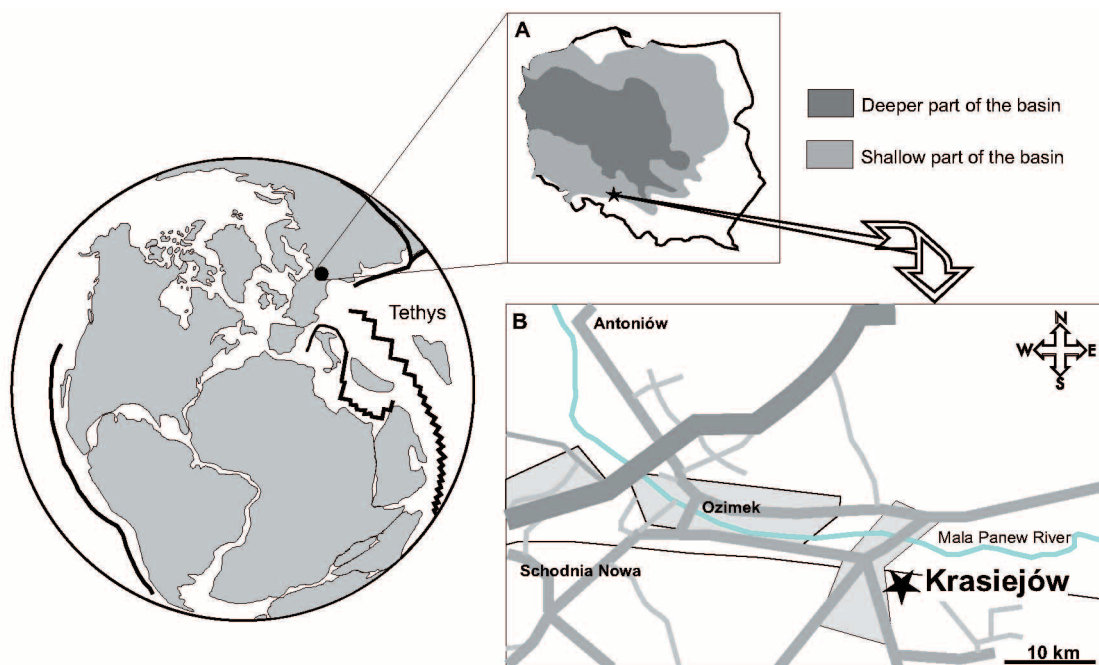


Fig. 1. Map of Poland with position of the site investigated (after DZIK & *al.* 2000) on the background of Pangea (after REINHARDT & RICKEN 2000)

The section sampled comprises four beds, distinguished on the basis of their colour (Text-fig. 2). The lowermost part of the section consists of dark red claystone, which is overlain by grey claystone with numerous remains of Triassic vertebrates (DZIK & *al.* 2000). Carbonate nodules occur at the bottom of this bed. The grey claystone are followed by a unit of dark red claystone, with a bivalve moulds accumulation at the top. Calcareous nodules in this bed may also contain bone fragments (see Text-fig. 2). The grey claystone along with the dark red one, is the bone-bearing bed. The highest bed investigated consists of light grey mudstone. Higher up, these two different coloured lithologies alternate in a characteristic cyclic pattern.

The age and correct stratigraphical assignment of the beds investigated are somewhat problematic. The lack of determinable megaspores (Dr. Paweł FILIPIAK, personal communication) prevents precise dating by palynological methods. The lithology, charophyte-ostracod association and plant fragments attest that sediments at Krasiejów could have developed in the Late Keuper during deposition of the highest part of the Reed Sandstone and/or Upper Gypsum Beds (DECZKOWSKI 1977). At the end of the Reed Sandstone sedimentation, progressive dry climate contributed to an increase in mottled mudstones and claystones. The lower part of the Upper Gypsum Beds has an almost identical lithology (DECZKOWSKI 1977), which impedes determination of the boundary between these two formations. DECZKOWSKI (1977) and

KOPIK (1973) reported similar lithology, as well as charophyte-ostracod association and plant remains in the lowermost part of the Jarkowo beds (Earliest Rhaetian) of the Silesia-Cracow and Kalisz-Częstochowa regions. In addition, the Keuper/Rhaetian boundary cannot always be determined unambiguously (DECZKOWSKI 1977, GAJEWSKA 1978). At the turn of the Keuper/Rhaetian, the onset of erosion resulted in different Rhaetian formations resting on different Keuper sediments in many regions of the Polish Lowland (DECZKOWSKI 1977, GAJEWSKA 1978).

The bone bed, on the basis of the occurrence of the characteristic phytosaurs *Paleorhinus* as well as the temnospondyl amphibians *Metoposaurus diagnosticus* (DZIK & *al.* 2000; DZIK 2001; SULEJ 2002), has been assigned to the *Paleorhinus* biochron (HUNT & LUCAS 1991). The *Paleorhinus* assemblage (sensu LUCAS 1998) is of great biochronological significance for the whole of Pangea (HUNT & LUCAS 1991). The bone-bearing bed corresponds to the Drawno Beds (SULEJ 2002) and lies ca. 80 m above the top of the Reed Sandstone – the counterpart of the German Schilfsandstein Formation, which contains a similar vertebrate assemblage. The radiometric dating of the Schilfsandstein (KÖPPEN & CARTER 2000) suggests a Middle Carnian ( $224 \pm 15$  Ma) age. However, these fission track data seem to be quite unprecise, because the subtraction or addition of 15 Ma results in a Late Norian or a Late Ladinian age respectively (CHANNELL & *al.* 2003, fig. 14; Dr. Heinz KOZUR, personal communica-

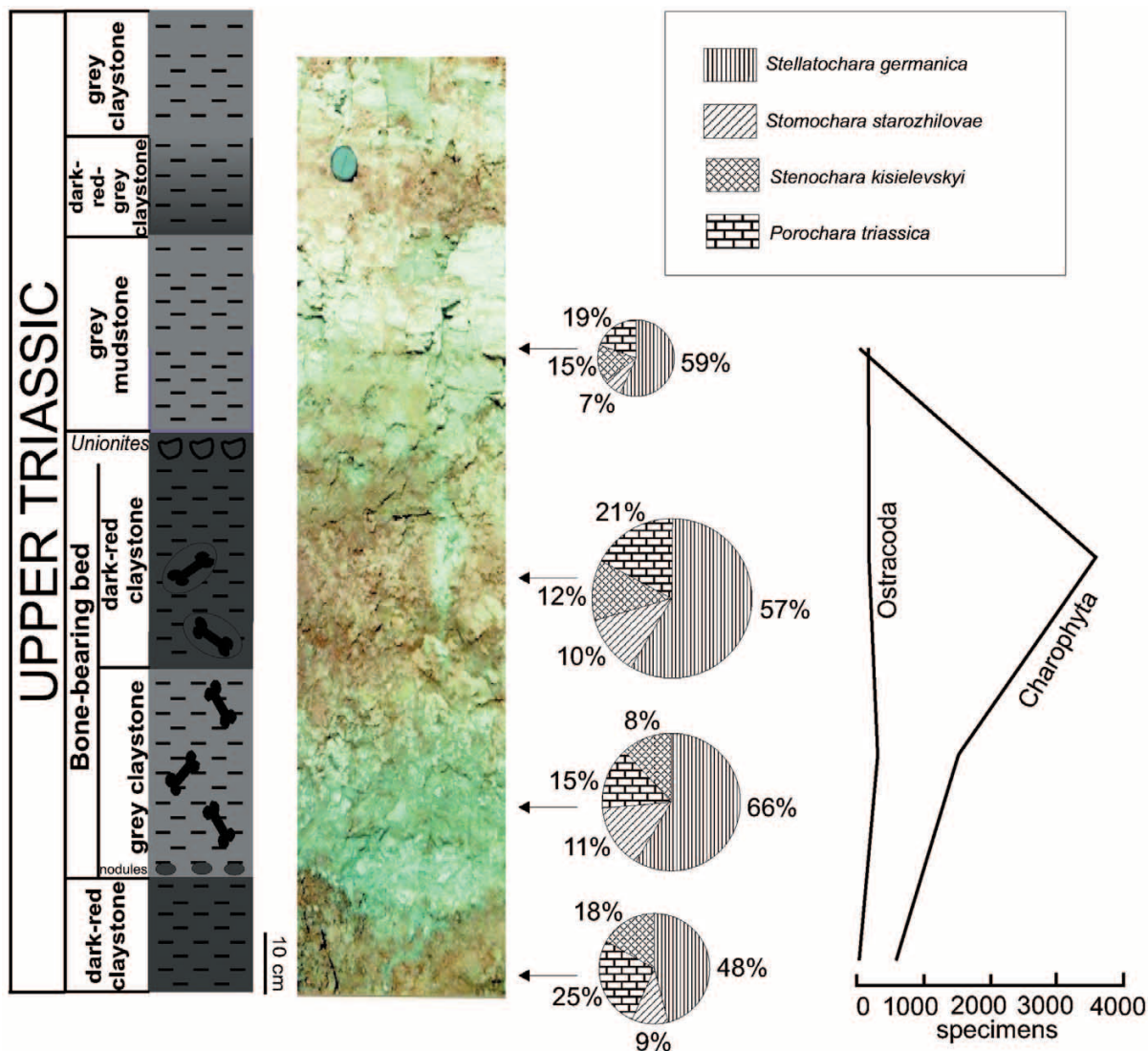


Fig. 2. Stratigraphy of the beds investigated at Krasiejów, with proportions of the charophyte species, and charophyte and ostracod quantities per kilogram of sediment. Photo taken by Dr. Wojciech KRAWCZYŃSKI

tion). DZIK & *al.* (2000) proposed a Late Carnian age, which seems correct. Moreover, the phytosaur *Paleorhinus* has been found in Austria in marine deposits of Late Carnian age (LUCAS 1998). It is clear that vertebrates are the most precise stratigraphical tool for determination of the age of the deposits at Krasiejów.

## MATERIAL AND METHODS

Four samples have been taken from the environs of the bone-bearing bed at Krasiejów. After drying, each sample was weighed to one kilogram of sediment. Each sample was then disaggregated with a solution of Glauber salt. The samples were washed in 0.03, 0.25 and

0.315 mm sieves. After drying the fractions at 80 °C, the gyrogonites, ostracods, and tiny vertebrate teeth were picked under a binocular microscope. The charophyte remains were determined to species level if possible, and the total number of gyrogonites as well as the percentage amount of all taxa was established. The number of gyrogonites per kilogram of sediment varied from several (26 specimens only) to more than three thousand specimens.

The specimens selected were photographed at the Scanning Laboratory of the Department of Earth Sciences in Sosnowiec, using a Philips environmental scanning electron microscope. The taxonomy of the gyrogonites was determined using morphological observations, as well as biometric analyses based on BILAN (1974, 1988) and SOULIÉ-MÄRSCHÉ (1998).



Three powdered samples (grey and dark red clay-stones from bone-bearing bed and overlying grey mud-stone) were used for preliminary mineralogical analysis. XR diffraction analysis of the clay minerals was carried out using a Philips 3710 roentgen diffractometer at the Department of Earth Sciences in Sosnowiec.

## PREVIOUS INVESTIGATIONS OF LATE TRIASSIC CHAROPHYTES IN POLAND

The occurrence of charophyte gyrogonites in the Upper Triassic has been recorded by several authors. SZYPERKO-ŚLIWCZYŃSKA (1961) investigated the Upper Triassic deposits from north-eastern Poland, and described the occurrence of an abundant microflora as well as a charophyte-ostracod assemblage in clayey beds of (probable) Rhaetian age. ODRZYWOLSKA-BIEŃKOWA (1962) described two species of gyrogonites from Keuper deposits from the former Kielce province (Ślężany 1L borehole), and SENKOWICZOWA (1973), in a study of the fauna and flora characteristic of the Keuper of the Silesia-Cracow area, distinguished gyrogonites of the genera *Porochara*, *Stenochara* and *Stellatochara*. KOPIK (1973) and DECZKOWSKI (1977) mentioned some charophyte remains typical of the mottled clayey deposits of the Lower Rhaetian Jarkowo and Zbąszynek Beds. DECZKOWSKI (1977) noted the presence of gyrogonites at the boundary between the Reed Sandstone and Upper Gypsum Beds in the Kalisz-Częstochowa region. GAJEWSKA (1978) also noted charophyte gyrogonites from the Upper Gypsum Beds. MARCINKIEWICZ (1979) found gyrogonites throughout the Keuper strata.

BILAN (1969, 1974) exclusively investigated the Triassic charophytes in Poland and, on the basis of data from 80 boreholes throughout the country (BILAN 1988), described 8 genera and 52 species.

## MORPHOTYPES AND BIOLOGICAL SPECIES

The taxonomy of recent charophytes is based upon the morphology of the thalli (DAMBSKA 1964, GARCÍA 1994). The gyrogonites are not taken into consideration in species determination. However, in the fossil state, the gyrogonites are mostly the only elements of charophytes that become fossilized. In the case of young and well preserved Quaternary gyrogonites, which have living counterparts, identification of species is possible (compare HAAS 1999). For example, in two species of charophytes – *Nitella syncarpa* KÜTZING and *N. opaca* AGARDH – the oospores differ in colour (ELKHIATI & *al.* 2002). The species *Chara strigosa* A. BRAUN possesses black, velvet

oospores (Dr. Andrzej HUTOROWICZ, personal communication). It is widely known that the colour is not usually preserved during fossilization, especially in older deposits. Moreover, the oospores are very variable in shape even within the same charophyte species. It must be stressed that the gyrogonite is only the calcified remain of the fertilized female gametangium. A single plant could provide more than 100 gyrogonites, calcification of which occurs at different times in the same plant (GARCÍA 1994). The extreme example is *Chara contraria* A. BRAUN ex KÜTZING, which has on the same thalli oospores varying in shape from short and round to elongate and slim (Dr A. HUTOROWICZ, personal communication). Changes in gyrogonite dimensions could be produced by stressed conditions, which have been observed in the case of the above-mentioned species (GARCÍA 1994). In *Chara aspera*, on the other hand, the gyrogonites are more elongated in fresh waters (SOULIÉ-MÄRSCHÉ 1991). Therefore the taxonomy (parataxonomy) of fossil charophytes on the basis of their calcitic oogonia, especially of extinct groups, will not always show natural species (compare BERGER 1999); and it is therefore probable that some described Triassic species are synonyms, when they have exactly the same stratigraphical range.

GARCÍA (1994, 2003) stressed that at least 100 gyrogonites of each taxon are needed in order to recognize intra-population variability. As is shown on Text-fig. 2, many more than 100 gyrogonites were used for morphological observations. The standard measurable parameters (length, width and ISI index) of all morphotypes (by morphotype we mean any previously described species present in our samples) were tested statistically using *test d* (ELLIOTT 1977). The ISI index concerns the shape of the gyrogonites, and is expressed as  $\text{length/width} \times 100\%$  (see BILAN 1988). This test uses mean values and variations for each of the above variables. The difference between the mean values of all morphotypes is statistically significant at 5 % ( $p = 0.05$ ), 1 % ( $p = 0.01$ ) and even at 0.1 % ( $p = 0.001$ ), which means that all morphotypes differ from each other significantly enough to be separate species. First, we found in the samples all previously described species. Then, we tested each morphotype with another one within distinct genus, as well as amongst all genera. However, as mentioned above, the gyrogonites of the same species or even of the same thalli are highly variable. Therefore, we decided to test modern gyrogonites to see if they also differed significantly. We chose two populations of *Lamprothamnium papulosum* (WALLROTH) J. GROVES from the Early Holocene of Mauritania, because of the many observable morphotypes of this species (SOULIÉ-MÄRSCHÉ 1998). In this case *test d* also showed a significant difference between

these populations at 1 % (length) and 0.1 % (width and ISI). It is now clear that statistically significant variations between different morphotypes of gyrogonites must not be species determinants. We therefore grouped all morphotypes (all previously described species present in our assemblages) into four species, on the basis of non-measurable features, especially the character of the apical pole. We think that this determination is methodologically more parsimonious.

It may thus be assumed that distinct intra-population variability occurs, and is caused primarily by environmental conditions (GARCÍA 1994).

#### CHARACTERISTICS OF CHAROPHYTE SPECIES FROM KRASIEJÓW

The Late Triassic charophytes from Krasiejów represent the extinct family Porocharaceae (BREUER 1988). They belong to four genera and four species (ZATOŃ & PIECHOTA 2003): *Stellatochara germanica* KOZUR & REINHARDT, *Stomochara starozhilovae* (KISIELEVSKY),

*Stenochara kisielevskyi* BILAN and *Porochara triassica* (SAIDAKOVSKY).

***Stellatochara germanica* KOZUR & REINHARDT** (Text-fig. 3A) – The gyrogonites are prolate, ovoidal to nearly spheroidal in shape, with the greatest width in the middle part. At the summit, spirals form the apical neck, which has a pentagonal or irregular apical opening. This neck-structure is characteristic of the genus *Stellatochara*. 8-10 concave spirals with low interspiral ridges are visible in lateral view. The basal pole is rounded, with a small pentagonal opening. This species occurs in the uppermost Anisian and the Ladinian of Germany (KOZUR & REINHARDT 1969), the Anisian of the East European Platform (SAIDAKOVSKY & KISIELEVSKY 1985), and the Röt – Lower Rhaetic of the Polish Lowland (BILAN 1988).

***Stomochara starozhilovae* (KISIELEVSKY)** (Text-fig. 3B) – The gyrogonites are ovoidal to prolate in shape. At the summit, the ends of the spirals form five denticles, a structure that is characteristic of the genus. The apical

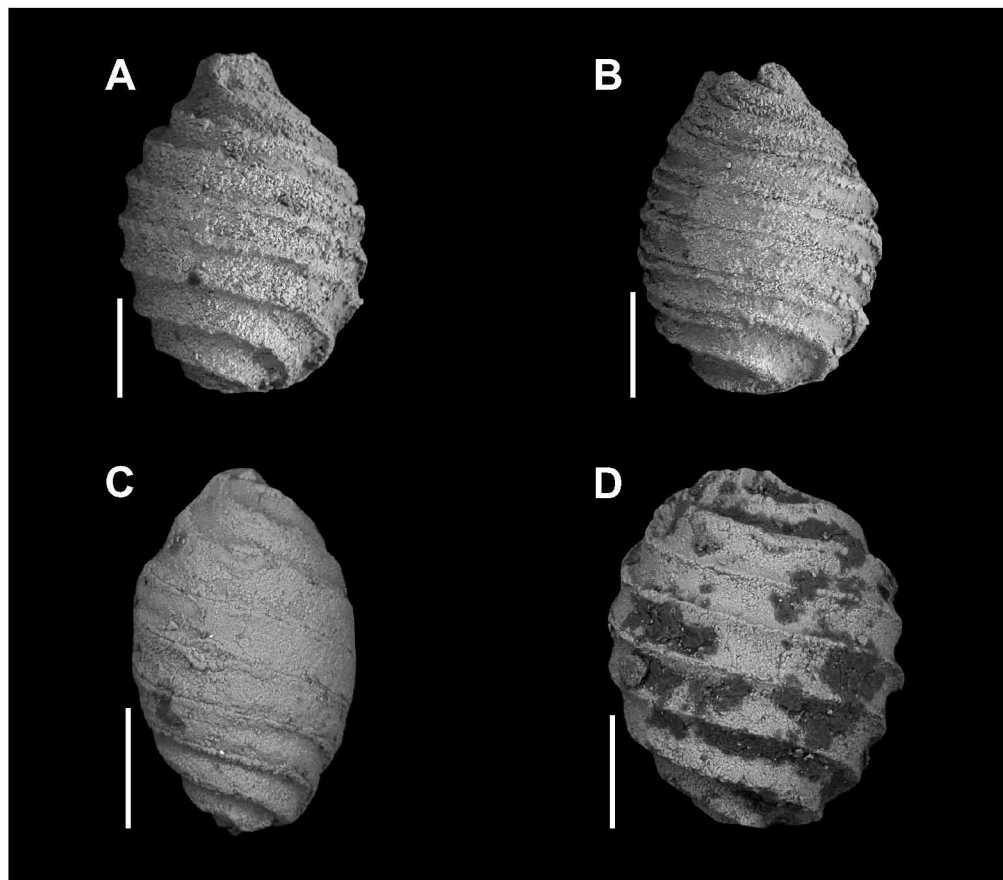


Fig. 3. SEM microphotographs of: A. *Stellatochara germanica* KOZUR & REINHARDT; B. *Stomochara starozhilovae* (KISIELEVSKY); C. *Stenochara kisielevskyi* BILAN; D. *Porochara triassica* (SAIDAKOVSKY). The scale bar is 100  $\mu$

opening is star-shaped. 7-10 generally concave or, to a lesser extent, flat spirals are visible in lateral view. The interspiral ridges are low. Each spiral possesses a distinct double suture. The basal pole is rounded or slightly conical, with a small pentagonal opening. This species occurs in the upper part of the Lower Triassic of the East European Platform (SAIDAKOVSKY & KISIELEVSKY, 1985), the Olenekian of Germany (KOZUR 1974), and the Middle Carnian and Lower Rhaetian of the Polish Lowland (BILAN, 1988).

*Stenochara kisielevskyi* BILAN (Text-fig. 3C) – The gyrogonites are ovoidal to prolate fusiform in shape. The apical pole is in the form of a low projection, but a slightly elongated or even an oblate shape also occurs. The apical opening is pentagonal or star-shaped. The basal pole may be rounded or elongated and in the shape of a truncated cone. Its opening is small-pentagonal or oval. 7-9 concave or flat spirals are visible in lateral view. The interspiral ridges of some specimens may possess a double suture. This species occurs in the Middle Buntsandstein – Lower Rhaetic in the Polish part of the Germanic Basin (BILAN 1988).

*Porochara triassica* (SAIDAKOVSKY) (Text-fig. 3D) – The gyrogonites are spheroidal to prolate spheroidal in shape. The apical pole is rounded with a pentagonal opening. The basal pole is also rounded, with a smaller pentagonal or oval opening. 7-10 spirals are visible in lateral view, with its the maximum width in the middle part of the gyrogonites. The interspiral ridges are distinct and sharp, less commonly blunted. This species occurs in the Lower and Middle Triassic of the East European Platform (KISIELEVSKY 1969) and Kazakhstan, as well as the Olenekian of Germany (KOZUR 1974). In the Polish part of the Germanic Basin it occurs in the Middle Buntsandstein – Lower Rhaetic interval (BILAN 1988).

## ECOLOGY OF RECENT CHAROPHYTES

Recent charophytes (stoneworts) generally belong to eurytopic organisms, as shown by their worldwide occurrence (DĄBBSKA & KAPIŃSKI 1954; CASANOVA & BROCK 1996). Firstly, they are associated with various types of fresh and brackish water reservoirs. Only a few species are found in saline basins. The most numerous representatives of charophytes appear in eutrophic lakes, fewer are present in oligotrophic lakes, and in dystrophic lakes they occur only sporadically (DĄBBSKA 1964; GARCÍA 1994). They grow mainly in shallow, alkaline freshwater lakes and ponds (see GARCÍA 1994), where

dissolved  $\text{CaCO}_3$  concentrations are  $100 \text{ mg l}^{-1}$ . Under these conditions, the photosynthetic activity of the charophytes causes calcification of the plant stems and fruiting bodies (which are then termed gyrogonites) usually, but not exclusively, with low Mg-calcite (ANDREWS & *al.* 2004). Gyrogonite calcification probably happens on a timescale of weeks (BECKER & *al.* 2002; ANDREWS & *al.* 2004).

Charophytes form a mono- or polyspecific phyto-coenosis, occurring in clusters or forming meadows. Apart from assemblages consisting of charophytes and vascular plants, we can find communities composed exclusively of charophytes. These algae are usually considered as indicators of clean, transparent waters (KRAUSE 1981), as well as the pioneer plant group colonizing the basins after various ecosystem events (COOPS 2002). The occurrence of this class of algae is dependent on several environmental factors, of which the most crucial are substrate, turbulence, salinity and insolation.

### Substrate and turbulence

The charophytes develop well on muddy-sandy and firm, muddy substrates. However, some taxa, like *Chara andina* (BRAUN) CÁCERES, can be found growing over gravel (GARCÍA 1994). They prefer calm, shallow basins; only sparse charophytes (e.g. *Chara fragilis* DESVAUX) settle in flowing waters (DĄBBSKA 1964; LANGANGEN 1974). The most crucial factor influencing the degree of settling on the basin floor is the chemical nature of the substrate. It was observed that recent representatives of *Chara* prefer calcareous substrates, while *Nitella* species prefer siliceous substrates (DĄBBSKA 1964). LANGANGEN (1974), on the basis of observations of Norwegian charophytes, stated that brackish species most often occur on sandy substrates.

### Salinity

Salinity is one of the main limiting factors of charophyte occurrence and reproduction. Usually an increase in salinity almost completely prevents the production of oospores (BONIS & GRILLAS 2002). However, halophyllic species that develop in water of increased salinity are known. The genus *Lamprothamnium* is typically found in saline habitats, as has been recorded from several different localities throughout the world (e.g. SOULIÉ-MÄRSCHÉ 1991; GARCÍA 1994; GARCÍA & CHIVAS 2004). The genus has a wide range of salinity tolerance, but is incapable of surviving at low salinities (see GARCÍA 1993). *Lamprothamnium papulosum*, for example, tolerates an increase in salinity to as much as 70 ‰ (SOULIÉ-MÄRSCHÉ 1998).

## Insolation

Light plays a significant role in the vertical distribution of charophytes. Although they appear in various bathymetric zones in lakes, different species have optimum growth in certain depth intervals (DĄBSKA 1964; LANGANGEN 1974). The mean for plant vegetation is 0-15 m (BHATIA & *al.* 1998), or 0-3 m (LANGANGEN 1974). Exceptionally it can be 30 m (BHATIA & *al.* 1998) or even 40 m (DĄBSKA 1964). An increase in depth of charophyte occurrence is related strictly to water turbidity (LANGANGEN 1974). Researches conducted in a New Zealand lake showed that charophyte occurrence in different depth zones is species-specific, and that light can markedly determine the lower boundary depth for these plants (SCHWARZ & *al.* 2002).

The bathymetrical distribution of charophytes is sometimes reflected in their morphology (DĄBSKA 1964; SCHWARZ & *al.* 2002). Species occurring at great depths are characterized by a lack of cortication of their thalli and by the simple structure of their branches. Shallow water species, on the other hand, have smaller sizes, stronger incrustation and are more fault-tolerant. This is undoubtedly related to the adaptation of charophytes to a more turbulent environment. Depth also has an influence on oospore incrustation (see DĄBSKA 1964).

## PALAEOECOLOGY OF TRIASSIC CHAROPHYTES FROM KRASIEJÓW

Even if LYELL's uniformitarian rule ("the present is the key to the past") is used carefully in relation to extinct organisms, it seems that it is nearly indispensable for the reconstruction of the environments of fossil organisms that have modern counterparts. It is similar for charophytes. Although in the Early Palaeozoic era their ecology could have been different, possibly even related to marine habitats (RACKI 1982), in Late Palaeozoic, Mesozoic and Cenozoic times the charophytes ecologically approached recent forms. They occur in non-marine facies, pointing to similar environmental parameters as those of modern charophytes. Therefore, knowledge of the ecology of recent charophytes is the first step to understanding the palaeoecology of the Triassic forms. The presence of gyrogonites in the sediment alone provides important information about the environment. In the deposits at Krasiejów, we can exclude a marine environment of sedimentation. In deposits close to the bone-bearing bed, the frequency of gyrogonites is very high – from several hundred per kilogram of sediment in the dark red claystone below the

bone-bearing bed unit to over 3000 per kilogram in the dark red claystone that forms the top of the bone-bearing unit. Such a high number of well preserved oospores attests to *in situ* fossilization (BHATIA & *al.* 1998). At Krasiejów there are also moulds of the aragonitic freshwater bivalve *Unionites* (DZIK & *al.* 2000) and the fresh or brackish water ostracods *Darwinula* and *Suchonella* (SCHUDACK & *al.* 1998; MEDINA & *al.* 2001; OLEMPKA 2004). Although recent brackish water charophytes mostly settle on sandy substrates (LANGANGEN 1974), the clayey sediments at Krasiejów provide evidence for a freshwater, probably lacustrine, environment (DZIK & *al.* 2000). The occurrence of abundant gyrogonites provides evidence that the charophytes settled in the illuminated parts of the basin (the photic zone). At the lower boundary of their occurrence, most charophytes reproduce only vegetatively (because of the lack of light) (DĄBSKA 1964; LANGANGEN 1974). Therefore the depth at which the charophytes grew was only a few metres. The depth of the basin, on the basis of the Late Triassic charophytes, is hard to determine, because the family Porocharaceae is extinct.

Since the dominant taxon is *Stellatochara* (Text-fig. 2), the whole charophyte assemblage around the bone-bearing bed can be assigned to a *Stellatochara* assemblage (*sensu* BILAN 1988). According to BILAN (1988), this assemblage, with co-occurring ostracods belonging to the genus *Darwinula*, is characteristic of reducing conditions prevailing on the basin floor (see also DZIK & *al.* 2000). OLEMPKA (2004) suggested that the low population densities of spinicaudatan crustaceans (conchostracans) from Krasiejów pointed to the unfavourable environmental conditions of a filling and stagnating pond.

Within the grey mudstone above the bone-bearing bed (Text-fig. 2), the frequency of gyrogonites drops drastically to 26 specimens per kilogram, while the frequency of ostracods remains the same as in the underlying bed. Since the occurrence of numerous and well preserved gyrogonites in the sediment may reflect equally numerous charophytes (BONIS & GRILLAS 2002), such a rapid decline in their frequency was undoubtedly caused by changes in environmental conditions. On the basis of the rather uniform frequency of ostracods that tolerate freshwater and mesohaline conditions (SCHUDACK & *al.* 1998), salinity could have played a very important role. An increase in energy of the environment can also be considered as a factor limiting charophyte abundance. SCHWALB & *al.* (2002) have recently observed an ostracod assemblage, consisting of e.g. *Darwinula*, in a high energy environment. However, charophytes prefer stagnant waters. Nevertheless, these two factors, salinity and energy of the environment, should have been responsible for charophyte decline.



## RESULTS OF PRELIMINARY MINERALOGICAL ANALYSIS

Quartz occurs as a major component in all the samples (average 40%). Calcite is ubiquitous in small quantities (up to 10%). Sodic and potassic feldspars occur as minor constituents in both the grey claystone and the light grey mudstone. Dolomite occurs in vestigial amounts (about 1%) in the same layers. Clay minerals make up about 45% quantity of each sample. Chlorite is the most common mineral in all the clay mineral assemblages. The grey and red claystones include muscovite, illite and illite-smectite mixed-layers. Illite, smectite and palygorskite were identified in the grey mudstone. The detrital clay minerals in the sediments show a weak diagenetic overprint because of moderate burial temperatures and the closed diagenetic system of the claystones (see AHLBERG & *al.* 2003).

Clay mineral formation through weathering is controlled by the chemistry of the parent rocks, the availability of water and drainage surface temperatures (YEMANE & *al.* 1996, RUFFELL & *al.* 2002). These point to a relationship between clay mineral assemblages, the climatic parameters which controlled the weathering of rocks, and the depositional environments (see CHAMLEY 1989; WEAVER 1989; INGLÉS & RAMOS-GUERRERO 1995; THIRY 2000). However, using exclusively clay mineral data as a proxy for palaeoclimate analyses are insufficient, all the more for samples from a few layers only. Nevertheless, the relative abundance of clay mineral species may be used as a first approximation to the palaeoclimate controls on sedimentation (see RUFFELL & *al.* 2002), in this case of the bone-bearing bed.

Chlorite is a major weathering mineral at high latitudes, mostly from crystalline rocks. This mineral frequently occurs in intermediate latitudes (YEMANE & *al.* 1996), where the climate varies from seasonally warm to cool and humid conditions. Chloritic material (especially the Mg-rich form) also may be formed in arid areas containing semi-closed depressions, where fresh water is periodically mixed with hypersaline brines (WEAVER 1989).

Illite (primarily detrital) is by far the most abundant phyllosilicate in Triassic sediments (WEAVER 1989). This mineral is unaffected by transport in rivers or in freshwater lakes (YEMANE & *al.* 1996). Illitic clays may be formed during seasons of warmer climates with lessened rainfall (AHLBERG & *al.* 2003).

Smectite and illite-smectite mixed layer are suggested to form during weathering in seasonally wet and dry climates (RUFFELL & *al.* 2002).

Palygorskite apparently formed during times of periodic desiccation. The occurrence of palygorskite, calcite

and dolomite suggests the availability of Mg (WEAVER 1989). The high Mg and Si concentrations necessary for their formation are supplied by weathering or from the sea (CHAMLEY 1989, WEAVER 1989). For the formation of palygorskite, dilution of sea water with fresh water is necessary. Palygorskite formed in brackish or lacustrine environments in warm and poorly drained regions submitted to long dry seasons (CHAMLEY 1989, WEAVER 1989). This mineral in marine sediments is either detrital or formed by the post-depositional circulation of brackish water.

## DISCUSSION

The Triassic was a time when large parts of the consolidated Pangean land masses (mainly between 40°N and 40°S latitude) were under the influence of a long dry season (VAN KONIJNENBURG-VAN CITTERT 2002, AHLBERG & *al.* 2003). During the Late Carnian, the Polish Basin was situated in the eastern part of the Germanic Basin, in the subtropical climatic zone. This part of Pangea was greatly influenced by monsoon circulation (REINHARDT & RICKEN 2000), leading to alternating humid and arid seasons.

The colour of sediments reflects the concentration of iron and manganese compounds in the matrix. The red coloration of the sediments is primarily due to the abundance of iron oxides accompanied by a low content of organic matter. The red colour is characteristic of better drained and oxidizing conditions. The grey colour, on the other hand, indicates iron depletion and usually is related to water saturation and reducing conditions during sediment formation (THERRIEN & FASTOVSKY 2000).

The mineralogical analysis points to arid to semi-arid conditions of deposition of the bone-bearing bed at Krasiejów, as well as the overlying beds. Carbonate nodules are known to occur in semi-arid climates where limited precipitation results in the incomplete leaching of carbonate from the soil (THERRIEN & FASTOVSKY 2000). The nodules and Fe oxides may be formed during periodical exposure to oxidizing conditions during the dry season (INGLÉS & RAMOS-GUERRERO 1995, WEAVER 1989). Also, the abundance of slightly weathered illites and chlorites and the scarcity of kaolinite and detrital vermiculite attest that the Late Triassic was predominantly a dry period, but generally with some seasonal rainfall (WEAVER 1989, RUFFELL & *al.* 2002). The abundance of gyrogonites and ostracods in all the beds investigated points to good hydrological conditions for their development. The only exception is the grey mudstone lacking bone remains, where the relative amount of gyrogonites drops drastically in contrast to that in the under-

lying beds. It may attest either to changes of climate (drying of the basin) or to an increase in salinity, as suggested by the presence of palygorskite.

We cannot unambiguously define the type of environment that prevailed during the deposition of the vertebrate remains at Krasiejów on the strength of mineralogical observations. On the one hand, the lack of evaporites suggests the existence of an open lacustrine system (INGLÉS & RAMOS-GUERRERO 1995; see also REINHARDT & RICKEN 2000). On the other hand, we cannot exclude the possibility that the beds in question developed in floodplain areas, where the degree of water saturation fluctuated (see THERRIEN & FASTOVSKY 2000). Nevertheless, both mineralogical and palaeobotanical analyses point to a basin where mixing of fresh water with sea water could have occurred. Reliable palaeoclimatic and palaeoenvironmental observations have to be supported by sedimentology and geochemistry as well as mineralogical analysis for the whole accessible section in Krasiejów.

## CONCLUSIONS

1. The diversity of the Late Triassic charophytes from Krasiejów is low. There are four species: *Stellatochara germanica* KOZUR & REINHARDT, *Stomochara starozhilovae* (KISIELEVSKY), *Stenochara kisielevskyi* BILAN and *Porochara sphaerica* KISIELEVSKY. They are characterized by a high degree of intra-population variability, and created the environmental background for other living animals.
2. The probable environment for the charophytes, and the other Late Triassic organisms living there, was a shallow (to a few metres deep), freshwater – most probable lacustrine - environment situated in a subtropical belt, with an alternating humid and arid warm climate. During the warm and humid climate, when the lake expanded, the algae could form vast charophyte meadows, such as during sedimentation of the bone-bearing bed. When conditions became more salty, or a high energy environment encroached, the charophyte communities declined. However, this palaeontological approach would be more robust, when combined with more extensive geochemical and sedimentological investigations.

## Acknowledgements

Warm thanks we direct to the journal referees Prof. Jerzy TRAMMER (University of Warsaw), Dr. Heinz KOZUR (Budapest, Hungary), and an anonymous reviewer, for their

critical remarks, which helped to improve the final version of this paper. We are grateful to Prof. Lubomira BURCHARDT and her team from the Department of Hydrobiology UAM in Poznań, as well as to Dr. Andrzej HUTOROWICZ, from the Institute of Inland Fisheries in Olsztyn, for the fruitful discussions about recent charophytes. Dr. Ewa OLEMPKA, from the Institute of Paleobiology of the Polish Academy of Sciences in Warsaw, is acknowledged for determination of the ostracods. Special thanks are due to Dr. Maria RACKA and Dr. Grażyna BZOWSKA for geochemical analysis, and to Ewa TEPER, M.Sc. for taking the SEM photographs. Dr. Dave BOND (University of Leeds, UK) has kindly improved the English language.

## REFERENCES

- AHLBERG, A., OLSSON, I. & ŠIMKEVIČIUS, P. 2003. Triassic-Jurassic weathering and clay mineral dispersal in basement areas and sedimentary basins of southern Sweden. *Sedimentary Geology*, **161**, 15-29.
- ANADÓN, P., UTRILLA, R. & VASQUEZ, R. 2000. Use of charophyte carbonates as proxy indicators of subtle hydrological and chemical changes in marl lakes: example from the Miocene Bicorn Basin, eastern Spain. *Sedimentary Geology*, **133**, 325-347.
- ANDREWS, J.E., COLETTA, P., PENTECOST, A., RIDING, R., DENNIS, S., DENNIS, P.F. & SPIRO, B. 2004. Equilibrium and disequilibrium stable isotope effects in modern charophyte calcites: implications for palaeoenvironmental studies. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **204**, 101-114.
- BECKER, D., PICOT, L. & BERGER J.-P. 2002. Stable isotopes ( $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$ ) of charophyte gyrogonites: example from the Brochene Fluh section (Late Oligocene – Early Miocene, Switzerland). *Geobios*, **35**, 89-97.
- BERGER, J.-P. 1999. Redefinition of European Oligo-Miocene Charophyte Biozonation. *Australian Journal of Botany*, **47**, 283-296.
- BHATIA, S.B., SOULIÉ-MÄRSCH, I. & GEMAYER, P. 1998. Late Pliocene and Early Pleistocene Charophyta floras of the Hirpur Formation, Karewa Group, Kashmir, India. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen*, **210** (2), 185-209.
- BILAN, W. 1969. Characeae from Keuper sediments of the Kolbark district. *Roczniki Polskiego Towarzystwa Geologicznego*, **39** (1-3), 433-454.
- 1974. Three new species of Charophyta from the Upper Triassic in the Cracow-Silesian region (Southern Poland). *Rocznik Polskiego Towarzystwa Geologicznego*, **44** (4), 483-489.
- 1988. The Epicontinental Triassic charophytes of Poland. *Acta Palaeobotanica*, **28** (1-2), 63-161.
- BONIS, A. & GRILLAS, P. 2002. Deposition, germination and spa-

- tio-temporal patterns of charophyte propagule banks: a review. *Aquatic Botany*, **72**, 235-248.
- BREUER, R. 1988. Zur taxonomischen Gliederung der Familie Porocharaceae (Charophyta). *Paläontologische Zeitschrift*, **62**, 3-10.
- CASANOVA, M.T. & BROCK, M.A. 1996. Can oospore germination patterns explain charophyte distribution in permanent and temporary wetlands? *Aquatic Botany*, **54**, 297-312.
- CHAMLEY, H. 1989. Clay Sedimentology. 1-624. *Springer*, Berlin.
- CHANNELL, J.E.T., KOZUR, H.W., SIEVERS, T., MOCK, R., AUBRECHT, R. & SYKORA, M. 2003. Carnian-Norian bio-magnetostratigraphy at Silická Brezová (Slovakia): correlation to other Tethyan sections and to the Newark Basin. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **191**, 65-109.
- COOPS, H. 2002. Ecology of Charophytes: an introduction. *Aquatic Botany*, **72**, 205-208.
- DĄMBSKA, I. 1964. Charophyta-Ramienice. 1-126. *PWN*; Warszawa.
- DĄMBSKA, I. & KAPIŃSKI, J. 1954. Ramienice. 1-35. *PWN*; Warszawa.
- DECZKOWSKI, Z. 1977. Budowa geologiczna pokrywy permско-mezozoicznej i jej podłoża we wschodniej części monokliny przedsudeckiej (obszar kalisko-częstochowski). *Prace Instytutu Geologicznego*, **82**, 1-63.
- DZIK, J. 2001. A new *Paleorhinus* fauna in the Early Late Triassic of Poland. *Journal of Vertebrate Paleontology*, **21**, 625-627.
- 2003. A beaked herbivorous archosaur with dinosaur affinities from the early Late Triassic of Poland. *Journal of Vertebrate Paleontology*, **23**, 556-574.
- DZIK, J., SULEJ, T., KAIM, A. & NIEDŹWIEDZKI, R. 2000. Późnotriasowe cmentarzysko kręgowców lądowych w Krasiejowie na Śląsku Opolskim. *Przegląd Geologiczny*, **48** (3), 226-235.
- ELLIOTT, J.M. 1977. Some methods for the statistical analysis of samples of benthic invertebrates. *Freshwater Biological Association, Scientific publication*, **25**, 1-160.
- ELKHIATI, N., SOULIE-MARSCHÉ, I., RAMDANI, M. & FLOWER, R. 2002. A study of the subfossil oospores of *Nitella opaca* (Charophyceae) from Megene Chitane (Tunisia). *Cryptogamie Algologie*, **23** (1), 65-73.
- GAJEWSKA, I. 1978. Stratygrafia i rozwój kajpru w północno-zachodniej Polsce. *Prace Instytutu Geologicznego*, **87**, 1-59.
- GARCÍA, A. 1993. Quaternary and recent *Lamprothamnium* groves (Charophyta) from Argentina. *Hydrobiologia*, **267**, 143-154.
- 1994. Charophyta: their use in paleolimnology. *Journal of Paleolimnology*, **10**, 43-52.
- 2003. *Lychnothamnus barbatus* (MEYEN) LEONHARDI from Australia: statistical analysis of its gyrogonite and comparison with European collections. *Acta Micropalaeontologica Sinica*, **20** (2), 111-117.
- GARCÍA, A. & CHIVAS, A.R. 2004. Quaternary and extant euryhaline *Lamprothamnium* Groves (Charales) from Australia: Gyrogonite morphology and paleolimnological significance. *Journal of Paleolimnology*, **31**, 321-341.
- HAAS, J.N. 1999. Charophyte population dynamics during the Late Quaternary at Lake Bibersee, Switzerland. *Australian Journal of Botany*, **47**, 315-324.
- HUNT, A.P. & LUCAS, S.G. 1991. The *Paleorhinus* biochron and the correlation of the non-marine Upper Triassic of Pangea. *Palaeontology*, **34** (2), 487-501.
- INGLÈS M. & RAMOS-GUERRERO E. 1995. Sedimentological control on the clay mineral distribution in the marine and non-marine Palaeogene deposits of Mallorca (Western Mediterranean). *Sedimentary Geology*, **94**, 229-243.
- KISILEVSKY, F. J. 1969. Novye vidy triasovykh kharofitov. *Voprosy Geologii Jugnogo Urala i Povolzia*, **5**, 26-32.
- KOPIK, J. 1973. - Retyk. In: S. SOKOŁOWSKI, S. CIEŚLIŃSKI & J. CZERMIŃSKI (Eds), Budowa geologiczna Polski, T. 1. Stratygrafia.. Mezozoik, pp. 88-93. *Instytut Geologiczny; Wydawnictwo Geologiczne*.
- KOZUR, H. 1971a. Ökologisch-fazielle Probleme der Biostratigraphie des Oberen Muschelkalks. *Freiberger Forschungshefte, C* **267**, 129-154.
- 1971b. Zur Verwertbarkeit von Conodonten, Ostracoden und anderen Mikrofossilien für stratigraphische und ökologisch-fazielle Untersuchungen in der Trias. *Geologický Zborník, Geologica Carpathica*, **22** (1), 105-130.
- 1972. Die Bedeutung der Megasporen und Characeen-Oogonien für stratigraphische und ökologisch-fazielle Untersuchungen in der Trias. *Mitteilungen der Gesellschaft der Geologie und Bergbaustudenten in Oesterreich*, **21** (1), 437-454.
- 1974. Probleme der Triasgliederung und Parallelisierung der germanischen und tethyalen Trias. Teil 1, Abgrenzung und Gliederung der Trias. *Freiberger Forschungshefte*, **298**, 139-197.
- KOZUR, H. & MOSTLER, H. 1972. Die Bedeutung der Mikrofossilien für stratigraphische, paläoökologische und paläogeographische Untersuchungen in der Trias. *Mitteilungen der Gesellschaft der Geologie und Bergbaustudenten in Oesterreich*, **21** (1), 341-360.
- KOZUR, H. & REINHARDT, P. 1969. Charophyten aus dem Muschelkalk und dem Unteren Keuper Mecklenburgs und Thüringens. *Monatsberichte der Deutschen Akademie der Wissenschaften zu Berlin*, **11** (5-6), 369-386.
- KÖPPEN, A. & CARTER, A. 2000. Constraints on provenance of the central European Triassic using detrital zircon fission track data. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **161**, 193-204.
- KRAUSE, W. 1981. Characeen als Bioindikatoren für den Gewässerzustand. *Limnologica*, **13**, 399-418.
- LANGANGEN, A. 1974. Ecology and distribution of Norwegian charophytes. *Norwegian Journal of Botany*, **21**, 31-52.
- LUCAS, S.G. 1998. Global Triassic tetrapod biostratigraphy and

- biochronology. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **143**, 347-384.
- MARCINKIEWICZ, T. 1979. Oogonia – gyrogonity. In: L. MALINOWSKA (Ed.), Budowa geologiczna Polski. Atlas skamieniałości przewodnich i charakterystycznych. Trias, 3(2a), pp. 157-159. *Wydawnictwa Geologiczne*; Warszawa.
- MEDINA, F., VACHARD, D., COLIN, J.P., OUARHACHE, D. & AHMAMOU, M. 2001. Charophytes et ostracodes du niveau carbonaté de Taourirt Imzilen (Membre d'Agleg, Trias d'Argana); implications stratigraphiques. *Bulletin de l'Institut Scientifique, Rabat, section Sciences de la Terre*, **23**, 21-26.
- ODRZYWOLSKA-BIEŃKOWA, E. 1962. Wyniki badań mikropaleontologicznych kajpru w otworze Ślężany 1L. *Kwartalnik Geologiczny*, **6** (2), 299-307.
- OLEMPKA, E. 2004. Late Triassic spinicaudatan crustaceans from southwestern Poland. *Acta Palaeontologica Polonica*, **49** (3), 429-442.
- RACKI, G. 1982. Ecology of the primitive charophyte algae; a critical review. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen*, **162**, 388-399.
- REINHARDT, L. & RICKEN, W. 2000. The stratigraphic and geochemical record of Playa Cycles: monitoring a Pangaeen monsoon-like system (Triassic, Middle Keuper, S. Germany). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **161**, 205-227.
- RUFFELL, A., MCKINLEY, J.M. & WORDEN, R.H. 2002. Comparison of clay mineral stratigraphy to other proxy palaeoclimate indicators in the Mesozoic of NW Europe. *Philosophical Transactions of the Royal Society of London*, **360**, 675-693.
- SAIDAKOVSKY, L.J. & KISIELEVSKY, F.J. 1985. Znachenie kharovykh vodoroslei dlia stratigrafii triasa Vostochno-Evropeiskoi platformy. In: A.V. VOSTRIAKOV (Ed.), Triasovye otlozheniia Vostochno-Evropeiskoi platformy. *Izdatelstvo Saratovskogo Universiteta*; Saratov.
- SCHUDACK, M.E., TURNER, C.E. & PETERSON, F. 1998. Biostratigraphy, paleoecology and biogeography of charophytes and ostracodes from the Upper Jurassic Morrison Formation, Western Interior, USA. *Modern Geology*, **22**, 379-414.
- SCHWALB, A., STEPHEN, B.J., CUSMINSKY, G., KELTS, K. & MARKGRAF, V. 2002. Assemblage diversity and isotopic signals of modern ostracodes and host waters from Patagonia, Argentina. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **15**, 323-339.
- SCHWARZ, A.M., WINTON, M. & HAWES, J. 2002. Species-specific depth zonation in New Zealand charophytes as a function of light availability. *Aquatic Botany*, **72**, 209-217.
- SENKOWICZOWA, H. 1973. Trias pozakarpacki (kajper) i Niż Polski (kajper). In: S. SOKOŁOWSKI, S. CIEŚLIŃSKI & J. CZERMIŃSKI (Eds), Budowa geologiczna Polski, T. 1. Stratygrafia. Mezozoik. *Instytut Geologiczny*, pp. 25-26, 87-88. *Wydawnictwa Geologiczne*; Warszawa.
- SOUILLÉ-MÄRSCHKE, I. 1991. Charophytes as lacustrine biomarkers during the Quaternary in North Africa. *Journal of African Earth Sciences*, **12**, 341-351.
- 1998. Fossil *Lamprothamnium papulosum* (Charophyta), a biomarker for seasonal rainfall in northern Mauritania. In: K. HEINE (Ed.), *Palaeoecology of Africa and surrounding islands*, **25**, 65-76.
- SULEJ, T. 2002. Species discrimination of the Late Triassic temnospondyl amphibian *Metoposaurus diagnosticus*. *Acta Palaeontologica Polonica*, **47** (3), 535-546.
- 2005. A new rauisuchian reptile (diapsida: archosauria) from the Late Triassic of Poland. *Journal of Vertebrate Paleontology*, **25** (1), 78-86.
- SULEJ, T. & MAJER, D. 2005. The Temnospondyl amphibian *Cyclotosaurus* from the Upper Triassic of Poland. *Palaeontology*, **48** (1), 157-170.
- SZYPERKO-ŚLIWCZYŃSKA, A. 1961. W sprawie wieku "brekcji lisowskiej". *Kwartalnik Geologiczny*, **5** (2), 329-337.
- THERRIEN, F. & FASTOVSKY, D.E. 2000. Paleoenvironments of Early Theropods, Chinle Formation (Late Triassic), Petrified Forest National Park, Arizona. *Palaios*, **5** (15), 194-211.
- THIRY, M. 2000. Palaeoclimatic interpretation of clay minerals in marine deposits: an outlook from the continental origin. *Earth-Science Reviews*, **49** (1-4), 201-221.
- VAN KONIJNENBURG-VAN CITTERT, J.H.A. 2002. Ecology of some Late Triassic to Early Cretaceous ferns in Eurasia. *Review of Palaeobotany and Palynology*, **119**, 113-124.
- WEAVER, C.M. 1989. Clays, Muds and Shales. *Developments in Sedimentology*, **44**, 1-820. Elsevier; Amsterdam – London – New York.
- YEMANE, K., KAHR, G. & KELTS, K. 1996. Imprint of post-glacial climates and palaeogeography in the detrital clay mineral assemblages of an Upper Permian fluviolacustrine Gondwana deposit from northern Malawi. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **125**, 27-49.
- ZATOŃ, M. & PIECHOTA, A. 2003. Carnian (Late Triassic) charophyte flora of the *Paleorhinus* biochron at Krasiejów (SW Poland). *Freiberger Forschungshefte*, **C499**, 43-51.